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Shipboard Evaluation of a Chlorinator/Macerator Sanitary Waste-Water Treatment System   Report 28-939

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20034

SHIPBOARD EVALUATION OF A CARLSON MARK 10 CHLORINATOR/ MACERATOR SANITARY WASTE-WATER TREATMENT SYSTEM

by
Craig S. Alig

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MATERIALS DEPARTMENT
Annapolis
RESEARCH AND DEVELOPMENT REPORT

May 1974   Report 28-939

The Naval Ship Research and Development Center is a U. S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland with the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
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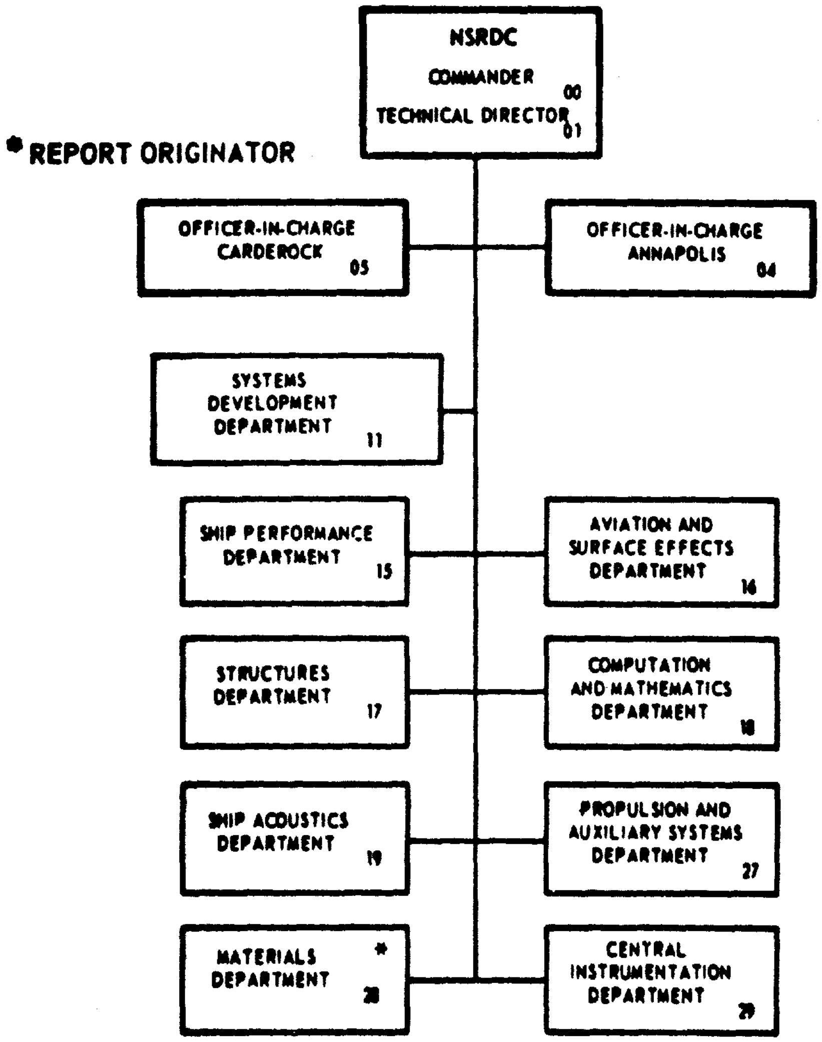

DEPARTMENT OF THE NAVY
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ADMINISTRATIVE INFORMATION

This work was accomplished under Work Unit 2860-525.

A test and evaluation plan was developed for NAVSHIPS, reference (a). The Center was tasked with conducting the evaluation and preparing a final report. This report fulfills that commitment and is in compliance with milestones as set forth in reference (b). Navy on-site support of field work was coordinated through COMINEWARFOR TWO, Charleston Naval Base, Charleston, South Carolina. Portions of the analytical laboratory work cited in the text were performed contractually under reference (c). Maintenance and Material Management and Consolidated Casualty Report System data were provided in reference (d) for the maintainability demonstration. References (e), (f), and (g) detail specific events of debugging and testing during the evaluation period.

ADMINISTRATIVE REFERENCES

(a) Schaller, C., "NAVSHIPS Test and Evaluation Plan for the Carlson Mark 10 Chlorinator-Macerator Sewage Treatment System Installed on the USS FIDELITY (MSO 443)," NAVSEC test plan, code 6159B (1973)
(b) NAVSEC Work Request 3-5666 of 28 Mar 1973
(c) LANTNAVFACENGCOM Contr N62470-73-C-1624 amended, 18 Oct 1972
(d) NAVSHIPS ltr 0451:JH, ser: 166-045 of 6 Mar 1973
(e) NSRDC Msg 011745Z of June 1973
(f) NSRDC Msg 091645Z of July 1973
(g) NSRDC Msg 301852Z of July 1973

ACKNOWLEDGMENTS

Appreciation is extended to the officers and enlisted men of the USS FIDELITY (MSO 443) and COMINEWARFOR TWO for their assistance and cooperation.

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INTRODUCTION

This is a final report on the shipboard technical evaluation of the Carlson Mark 10 chlorinator/macerator (C/M) sewage treatment system to determine its capability to pass the performance and mechanical reliability tests as required in MIL-S-24201B (SHIPS) of 7 April 1972, and the test and evaluation plan provided by NAVSEC. Compliance with the Environmental Protection Agency (EPA)[1] and United States Coast Guard (USCG)[2] performance standards for marine sanitation devices will also be discussed brieny.

The system that was evaluated is installed aboard USS FIDELITY (MSO 443), home ported at the Charleston Naval Base, Charleston, South Carolina.

OBJECTIVES

The objective of the evaluation is to provide data to determine whether the chlorinator-macerator complies with the following performance and reliability/ maintainability criteria.

The unit under evaluation must:

- Be capable of collecting, treating, and discharging sanitary waste.
- Pass performance tests as required by MIL-S-24201B (SHIPS) of 7 April 1972.
- Demonstrate a mean time between failure (MTBF) of 500 hours at a 90% confidence level.
- Demonstrate a maximum repair time of 5 hours during the reliability evaluation.
- Demonstrate a maximum time to repair (MTTR) of 5 hours, based upon the analysis of 10 corrective maintenance (CM) actions performed for the maintainability demonstration.

BACKGROUND

The Navy has been developing shipboard sewage treatment systems for over 8 years. The early stages [illegible] this program included the development of military specifications for the oper[illegible] [illegible]nator/macerator systems under the U.S. Public Health Guidelines of [illegible].

[1]Superscripts refer to similarly numbered entries in the technical references at the end of the text.

Initial specifications were developed as MIL-S-24201A(SHIPS) of 10 December 1968. The effluent bacteriological standards contained therein required a most probable number (MPN) coliform density count of zero for each of 10 chlorinated effluent samples tested. An extensive evaluation and statistical study in 1969 recommended the specifications be revised and proposed new specifications on the performance of MIL-S-24201(SHIPS) type C/M systems. These required a reduction in 90% of the sample runs from a coliform density of 10^7/100 ml* in untreated sanitary wastes to a density no greater than 1000/100 ml in the chlorinated effluent.[4]

Military specification MIL-S-24210(SHIPS) of 10 December 1968 was later revised to MIL-S-24210B(SHIPS) of 7 April 1972. This new specification which is currently in effect requires that a C/M be able to reduce the expected coliform MPN density of raw macerated sanitary waste from a magnitude ranging between 10^7 and 10^8/100 ml to 240 (or less)/100 milliliters.

Current EPA performance standards for marine sanitation devices require existing treatment systems on vessels to reduce fecal coliform bacteria to no more than 1000/100 ml and prevent the discharge of an effluent with visible floating solids.

DESCRIPTION OF SYSTEM

EQUIPMENT

The Carlson Mark 10 sewage treatment system consists of three basic subsystems, the control, chlorination, and maceration systems.

The control subsystem operates as follows: a control panel receives an electrical signal indicating operation of a water closet or urinal. Through a series of timers and relays, the panel governs the running time of the chlorine injection pump and macerator motors. A liquid-level control box monitors the disinfectant level in the chlorine storage tank. It provides the operator with a visual and audible alarm and deactivates the macerator if the disinfectant level in the tank runs low. This acts as a fail-safe device by preventing unchlorinated waste from being discharged overboard. An overload-jam relay shuts down the macerator motor if a foreign object enters the macerator tank and jams the blades. A "jam relay tripped" pilot light and reset button are located on the face of the control panel along with macerator and injection pump on/off switches, figure 1. Activation of a treatment cycle is accomplished by flow switches, figure 2, installed in the salt-water flushing line of each water closet or urinal connected to the system.

The chlorination subsystem consists of a 35-gallon disinfectant mixing tank, a 15-gallon storage tank, and a disinfectant injection pump, as shown in figure 3. The chlorine disinfectant solution is prepared by dissolving 29.2 pounds of granular

*Abbreviations used in this text are from the GPO Style Manual, 1973, unless otherwise noted.

calcium hypochlorite (70% available chlorine) in 25 gallons of water. After settling for 24 hours, the clear liquid is decanted from the mixing tank to the storage tank as needed. The storage tank is a reservoir for the chlorine disinfectant. From here it is pumped to the macerator/detention tank in controlled volumes for each flush.

The macerator subsystem consists of a 15-gallon macerator/detention tank, motor, and shaft equipped with three cutting blades to comminute the influent waste into fine particles. A trap is connected to the inlet side of the macerator to prevent heavy foreign objects from entering the tank and damaging the macerator, see figure 4.

OPERATION

Sanitary waste is collected in the urinals or water closets. When a flushometer is depressed, the flow switch signals the control panel that waste is entering the drain line. At the same time, disinfectant is injected into the macerator/detention tank. The volume of disinfectant is controlled by a relay which determines the running time of the injection motor and pump. The injection rate is preset to deliver approximately 225 ml of hypochlorite solution per flush. Immediately after the disinfectant is injected, the macerator motor begins to rotate shaft and blades at 3450 r/min for 55 seconds. The cylindrical housing around the macerator shaft acts as a baffle. When the blades are spinning, waste is forced along the axis of the shaft to the bottom of the tank, as illustrated in figure 5. This ensures thorough mixing of the influent with the disinfectant.

The macerator/detention tank has a 15-gallon capacity. Waste passes through the tank on an equal displacement basis. The degree of treatment is dependent upon the time interval between flushes and flush volumes. A long interval and small flush volume would increase detention time and improve treatment.

EVALUATION SITE

The primary reason for the selection of the Carlson Mark 10 chlorinator/macerator installed on USS FIDELITY was a scheduled period of restricted availability (RAV) prior to the anticipated start of the evaluation. It was, therefore, convenient for the required servicing of the equipment and the installation of a sample valve to be part of the RAV work.

The C/M system was originally installed in USS FIDELITY in 1969. It has forward and aft macerator tanks and control panels with a common chlorine mixing and storage tank. Each macerator has an individual chlorine injection pump mounted on the one chlorine supply tank.

For the purpose of this evaluation, the aft macerator was disconnected from the system and only the forward macerator was evaluated. This in no way affected the operation of the forward macerator or the conduct of the evaluation. Throughout this report, USS FIDELITY installation discussed is a single macerator unit serving the forward part of the ship only.

The C/M treats sanitary wastes from three water closets and two urinals in the crew's head, and one water closet in the captain's head. The equipment is located in a storage locker adjacent to the crew's berthing area. The treated effluent is discharged through a scupper valve. A schematic of the shipboard installation and piping diagram are shown in figures 6 and 7, respectively. The equipment was installed in existing plumbing with only the macerator/detention tank and trap being added to the ship's waste-water lines.

INVESTIGATION

TEST AND EVALUATION PLAN

The test and evaluation plan for the Carlson Mark 10 chlorinator/macerator was prepared by NAVSEC (SEC 6159B) in collaboration with Center personnel; see Administrative Information, page iv. The plan provides the methods for testing and delineates responsibilities for conduct of the performance test and reliability/ maintainability requirements.

Evaluation criteria require the system to pass the performance tests as required in MIL-S-24201B (SHIPS) of April 1972. This was to be demonstrated by operating the system for 10 consecutive runs per day (excluding weekends) treating waste of human origin, at the peak morning period for a minimum of 10 days to obtain samples for bacteriological examination. The MPN (confirmed) of coliforms in raw macerated waste ranging between 10^7 and 10^5/100 ml must be reduced to 240 (or less) /100 ml in at least 90% of all samples by maceration and dosing with a liquid solution containing 10% available chlorine by weight.

Further criteria required a MTBF of 500 hours at a 90% confidence level, a maximum repair time of 5 hours for each CM action performed during the reliability test, and a MTTR with 90% probability that at least 95% of the logs of the repair times will be less than the log of 5 hours, based upon the analysis of 10 CM actions performed for the maintainability demonstration.

PRETEST PREPARATION AND OPERATION

Prior to the start of the evaluation, the C/M had been secured due to a lack of spare parts needed to repair the equipment. These parts were procured and the equipment repaired through the assistance of SUPSHIPS SIX, Charleston, South Carolina, as part of on-going RAV work. C/M fixes included: replacement of the existing stainless steel chlorine injection line with neoprene hose that is more resistant to the corrosiveness of the disinfectant, replacement of a damaged chlorine injection pump, servicing the overboard discharge scupper valve, and installation of a sample valve between the macerator and overboard discharge.

Water meters were installed in the sea-water flush lines to the water closets and urinals, as shown in figure 6. Electromechanical flush counters and a macerator motor elapsed-time indicator were installed on the control panel.

An initial shake-down period was necessary to "break in" the equipment following its return to on-line treatment. Problems encountered in the automatic operation of the system during this period were as follows:

- The flow switches in the sea-water flush lines would not activate the equipment. Corrosion and deposits were discovered in the flow-switch springs and magnets exposed to the sea water. These parts were cleaned and/or replaced.

- The stainless steel check valve that connected the chlorine injection line to the top of the macerator tank was no longer functional. Its purpose was to prevent the back pressure generated in the tank during maceration from forcing waste into the injection line. The stainless steel valve was replaced by a polyvinyl chloride (PVC) valve.

- The PVC check valve located in the disinfectant storage tank on the end of the chlorine injection line was clogged. The valve was cleaned and restored to working order.

- The heavy neoprene hose used as the chlorine injection line was replaced by clear PVC hose of equivalent size. This was done only to facilitate the diagnosis of further chlorination problems by permitting the operator to observe the chlorine being pumped through the injection line. This change did not affect or alter system performance.

METHODS OF EVALUATION

Laboratory analyses were performed on samples collected by personnel of this laboratory during each macerator cycle for 10 consecutive cycles per day for 10 days. The samples were collected between 0600 and 0800 which was considered the peak morning use period. Fourteen additional samples of unchlorinated, macerated waste were also collected to assess the degree of treatment obtained by chlorination.

The sample port was located between the macerator tank and the overboard discharge on the underside of the effluent line.

Chlorinated effluent samples were collected during a macerator cycle immediately after chlorine injection. Half of the sample was collected in a sterile bottle containing sufficient sodium thiosulfate to neutralize residual chlorine. The other half of the sample was collected in a large container and a subsample was taken for analysis of residual chlorine. All samples were refrigerated between the collection/chlorine neutralization step and analysis.

The chlorine solution injection rate was maintained at 225 ml per flush. A 10% by weight solution of chlorine was obtained by dissolving 29.2 pounds of granular calcium hypochlorite (70% available chlorine) in 25 gallons of lukewarm water. Macerator running time was set at 55 seconds beginning immediately after chlorine injection.

Water meters were installed in the salt-water flush line, as shown in figure 6, to determine the hydraulic load on the system. The meter in the water closet flush line recorded the total flow to the three water closets in the crew's head and the water closet in the captain's head. The meter in the urinal flush line recorded total flow to the two urinals and the deep sink in the crew's head.

The valve in the sea-water flush line to the urinals had been secured prior to the start of the evaluation due to leaks in the drain lines. On 17 May the leaks were repaired and the valve was opened. It was then discovered that the flushometers leaked approximately 24 gallons of flush water per hour. Unsuccessful repair attempts resulted in the urinals being secured by the ship's crew on 7 June. It should also be noted that due to the location of flow switch 5 (FS-5), as shown in figure 6, the C/M was activated when the salt-water faucet in the head deep sink was opened. The sink drain, however, did not lead to the macerator tank. The flow switch was disconnected on 17 May and remained inoperable during the test. The effects of faulty urinal operation are apparent in the results presented later in this report.

Flush counters were installed on the C/M control panel to record total use of the system. Each time a water closet was flushed, the use was recorded on its counter.

Elapsed time indicators were also installed on the C/M control panel. Total system on-line time and macerator running time were recorded.

During the performance evaluation phase of the test, flush water volume, flush counts, and elapsed time were recorded every 4 hours by the personnel of this laboratory or the ship's crew on the log forms shown in appendix A. Recordings during the remainder of the 1150-hour test period were taken every 8 hours by ships forces operating the system.

Reliability demonstration information was maintained by both the on-site personnel of this laboratory and the ship's crew. Critical, major, or minor failures were recorded on a maintainability/human factors failure report form shown in appendix A, and each failure was verified by the project engineer.

Maintainability demonstration information comprised downtime for corrective maintenance actions documented on forms shown in appendix A, both during the reliability demonstration phase and the following maintainability demonstration. The CM actions performed during the test were carried out by the ship's crew. The additional CM repair actions not obtained during the reliability test but required by the test plan were induced or simulated immediately upon the conclusion of the 1150-hour period. Personnel involved in the maintainability, test induced or simulated failures were either ships' crew or Center personnel with skills comparable to those of a Navy technician who would normally perform the maintenance.

Analyses were performed on 10 CM actions to demonstrate compliance with the maintainability requirement. Selection of the induced/simulated failures was based

on malfunctions and probable causes outlined in the troubleshooting tables of the system operating manual.[5]

RESULTS

PERFORMANCE EVALUATION

A summary of the laboratory analyses of samples collected during the performance evaluation are presented in tables 1 and 2. All analyses were done in conformance with procedures described in Standard Methods.[6]

TABLE 1
SUMMARY OF LABORATORY ANALYSIS FOR COLIFORM BACTERIA

	Macerated Influent						Effluent					
	n	r	$G_{\bar{x}}$	>0	>240	>1000	n	r	$G_{\bar{x}}$	>0	>240	>1000
Total coliform bacteria, MF, colonies/100 ml	14	2.6×10^5 to 4.8×10^6	1.1×10^6	14	14	14	99	<10 to 10^6	19/67	44	27	19
Fecal coliform bacteria, MF, colonies/100 ml	14	9.6×10^4 to 2.5×10^6	3.8×10^5	14	14	14	99	<10 to 10^6	11/67	39	23	14
Total coliform bacteria, MPN, confirmed, colonies/100 ml	14	>1100	-	14	14	14	99	<3 to >1100	-	43	38	24
Fecal coliform bacteria, MPN, confirmed, colonies/100 ml	14	>1100	-	14	14	14	99	<3 to >1100	-	41	33	22

n = Number of samples tested.
r = Range of values for samples tested.
$G_{\bar{x}}$ = Estimates of the Geometric mean, minimum/maximum.
>0 = Number of samples with counts greater than 0.
>240 = Number of samples with counts greater than 240.
>1000 = Number of samples with counts greater than 1000.

TABLE 2
SUMMARY OF LABORATORY ANALYSES FOR SUSPENDED SOLIDS, SETTLEABLE SOLIDS, AND RESIDUAL CHLORINE

	Macerated Influent				Effluent			
	n	$\bar{x}$	s	95% cm	n	$\bar{x}$	s	95% cm
Total suspended solids, mg/l	14	785	743	785±389	99	773	579	773±114
Settleable solids, ml/l	14	63	50	63±26	99	69	36	69±7
Residual chlorine, p/m	-	-	-	-	99	156	129	156±25

n = number of samples tested.
$\bar{x}$ = arithmetic mean.
s = standard deviation.
95% cm = 95% confidence of mean.

Coliform bacteria counts were determined by two methods. The multiple tube fermentation technique yielding the most probable number (MPN) coliform bacteria results were used to determine system compliance with MIL-S-24201B (SHIPS) performance criteria. The membrane filter (MF) technique was used to supplement results obtained by the multiple tube method. For samples which had a coliform bacteria concentration less than the detection limit of 10 MF colonies/100 ml, assume that the true value approached 10 as an upper limit and 0 as a lower limit. Therefore, 10 is substituted to compute a maximum value for the geometric mean (worst case) and 1 was substituted to compute a minimum value (best case). Calculations are shown in Appendix B.

The results of effluent coliform determinations compared to requirements based upon C/M military specifications and proposed USCG regulations are as follows:

- Military specifications require that no more than 10% of the samples show an MPN (confirmed) greater than 240. Analysis of 99 effluent samples showed 38.4% greater than 240.

- Coast Guard proposed regulations require that the geometric mean of 20 samples show a fecal coliform MPN less than 1000. MF analyses showed a geometric mean of 11 for the best case and 44 for the worst case for 99 samples.

Water closet use during the 1150-hour test period is summarized in table 3. The data were obtained from meter reading, flush count, and elapsed time logs maintained by the Center's engineer on-site and the crew of FIDELITY.

Total use of the system during the 1150-hour test period was as follows:

- 1,150 hours of C/M on-line time.
- 47.8 hours of macerator running time.
- 5,258 flushes of the four water closets.

- 16,600 gallons of water closet flush water entered macerator.

- 14,900 gallons of water entered macerator through urinal drains while on-line.

TABLE 3
AVERAGE WATER CLOSET USE DURING TEST

	With Urinals in Use				Urinals Secured			
	Gallons Per Day	Flushes Per Day	Ship's Complement Using C/M System*		Gallons Per Day	Flushes Per Day	Ship's Complement Using C/M System*	
			0700-1630	Remaining Time			0700-1630	Remaining Time
Monday thru Friday	219	72.7	58-60	8-9	444	147	58-60	8-9
Saturday and Sunday	116	39.4	8-10	8-10	195	64.6	8-10	8-10

*From ship's muster counts.

RELIABILITY EVALUATION

The reliability of the C/M system was demonstrated during the 1150-hour test period. Critical and major failures and the total repair time spent from fault location through to final checkout are presented in table 4. The mean time to repair, as computed in table 1-C of appendix C, was 27 minutes. The maximum repair time was 280 minutes, which was within the 5-hour limit prescribed by the test plan. A chronological summary of events for the 1150 hours, including elapsed time and flush count readings, is in appendix B.

Computation of the mean time between failure for the eight failures in table 4, yield an MTBF of 88.5 hours at a 90% confidence level.[7] The test plan requires 1150 operational hours with no critical or major failures.

MAINTAINABILITY EVALUATION

The maintainability of the C/M system was demonstrated at the close of the 1150-hour test period. Analysis was performed on 10 corrective maintenance actions, as presented in table 5. The downtimes accumulated during the 1150-hour test were charged as CM downtime, with downtimes for similar failures being averaged and counted as one CM action each. The 10 actions and their associated active repair times are listed in table 5.

TABLE 4
CRITICAL AND MAJOR FAILURES DURING THE
1150-HOUR RELIABILITY EVALUATION

Failure	Active Repair Time, min
Critical, macerator clogged with paper towels and mop strings	280
Critical, empty disinfectant storage tank	5
Critical, empty disinfectant storage tank	5
Critical, clogged chlorine injection line	10
Major, leaky chlorine injection pump, pump still operational	30
Critical, macerator clogged with paper towels	120
Major, macerator r/min reduced due to electrician's tape tangled in blades	51
Critical, leaky chlorine injection pump, pump inoperative	19
Total Repair Time	520
Note: Failure times for similar failures were averaged and included as one failure for use in the maintainability evaluation.	

The six CM actions listed in table 5 that did not occur during the reliability test were simulated or induced failures. Center personnel involved in the maintainability demonstration were comparable in skill to the average Navy technician that would normally have performed the maintenance. Active repair times included the time spent from fault location through to final checkout.

An accept or reject decision is based upon a 90% probability that at least 95% of the logs of the repair times will be less than the log of the permissible MTTR of 5 hours. Computations yielding a reject decision based upon the 10 CM actions are shown in table 2-C of appendix C.

TABLE 5
CORRECTIVE MAINTENANCE ACTIONS FOR
MAINTAINABILITY DEMONSTRATION

Action	Active Repair Time min
1 - Correct liquid level in disinfectant holding tank	5
2 - Correct blockage in chlorine injection line	10
3 - Repair chlorine injection pump	25
4 - Correct macerator blade rotation	150
5 - Replace timer relay attachment on TR12	34
6 - Replace magnetic relay	19
7 - Replace injection pump motor bearings	58
8 - Repair liquid-level probe control circuit	56
9 - Replace inoperative flow switch components	40
10 - Replace lower macerator shaft bearing	173
Total Repair Time	570

1-4 inclusive - Performed during the reliability demonstration.
1-6 inclusive - Performed by the ship's crew.
7-10 inclusive - Performed by Center personnel.

DISCUSSION

ANALYSIS OF EFFLUENT COLIFORM BACTERIA DETERMINATIONS

Total and fecal coliform bacteria in the effluent were determined by the MPN and MF techniques. The results were analyzed to indicate conformance with military specifications as required by the test plan. The 10% limitation for samples with greater than 1000 coliform per 100 ml was exceeded. Therefore, the criteria contained in MIL-STD-24201B(SHIPS) were not satisfied for total coliform bacteria.

USCG effluent coliform standards were developed under EPA requirements for existing marine sanitation devices on United States owned and operated vessels.[1,2]

These require that the geometric mean of MPN fecal coliform bacteria discharged in the effluent be less than 1000/100 ml of effluent and that no more than one sample be collected during any consecutive 6-hour period. Additional criteria require that test conditions simulate those found on a vessel for a similar strength influent.

The military standard, for which the C/M was evaluated as required by the test plan, requires collecting 10 samples on each of 10 consecutive days. If more than 10% of the samples show a coliform MPN greater than 240/100 ml, the equipment should be rejected.

Both standards require that coliform determinations be expressed as MPN/100 milliliters. For the sample volumes used in the analysis of the 99 samples listed in appendix E, the detection limits determined by analytical sample volume were less than 3/100 ml and greater than 1100/100 milliliters. These limits presented no problems in data analysis for the military standard, but a statistical evaluation based on the USCG proposed standards is impossible when actual numerical values are not obtained.

An evaluation of the C/M against the USCG fecal coliform standard is possible if three assumptions are made. First, the conditions of the evaluation are comparable to those required by the standard. Second, the sampling schedule and number of samples can be accurately applied to the USCG formula. Third, the MF coliform test data is substitutable for MPN test data for the same samples.

The geometric mean for fecal coliform bacteria was computed for the best and worst cases as shown in appendix B. For the worst case in which the <10 values were computed as equaling 10, the geometric mean was 44/100 milliliters. This was well within the acceptable limit prescribed by USCG. However, the same coliform values applied to the military standard greatly exceeded the maximum acceptable values.

Therefore, for the Carlson Mark 4.0 chlorinator/macerator, the proposed USCG standards for fecal coliform are considerably more lenient than the current military specification standards. Their adoption would create less stringent standards than those currently enforced. This would result in accepting increased coliform bacteria discharges which could lead to a reduction in the quality of receiving waters.

OTHER ANALYTICAL DATA

Chlorination provided very little change in suspended or settleable solids. The mean value of total suspended solids, as shown in table 2, was only reduced 2% from 785 to 773 mg/liter. The mean value of settleable solids in the chlorinated samples was approximately equal to that obtained for the unchlorinated samples.

The residual chlorine present in the effluent could pose a potential threat to marine wildlife. The chlorine injection rate was 225 ml per flush. Average residual chlorine in the effluent was 156 p/m which greatly exceeded 0.1 p/m stated by the National Academy of Science as being hazardous to marine life.[8]

SYSTEM AND COMPONENT RELIABILITY

The reliability of the C/M system was demonstrated during the 1150-hour test period. A discussion of the failures during that period follows:

(1) Failure Mode - The macerator clogged on 17 May and 19 June. These failures were caused by paper towels and mop strings being flushed down the water closets. The jam relay light indicated that macerator shaft rotation was restricted, but the stoppage was not observed until the operator entered the sewage treatment room to read the flush counters.

Corrective Action - The problem was remedied by removing the macerator blade assembly and cleaning the blades. An audible alarm should be installed to signal a macerator failure. This would eliminate delays in recognizing that a failure exists.

(2) Failure Mode - A low liquid-level condition in the disinfectant storage tank on 18 and 25 May prevented chlorine from being pumped to the macerator/detention tank. These failures were due in part to both human error and equipment failure. The low level alarm for the disinfectant storage tank failed to indicate that the tank needed refilling.

Corrective Action - The low liquid-level problem was easily solved by transferring disinfectant solution from the mixing tank. Ship's personnel were not able to diagnose the reason for the alarm failure; so it was necessary to monitor the liquid level in the storage tank more carefully through the remainder of the test period.

(3) Failure Mode - The chlorine injection line clogged at the inlet to the macerator tank on 10 June. This was caused by the accumulation of granular, undissolved calcium hypochlorite being pumped from the bottom of the storage tank.

Corrective Action - By more thoroughly dissolving the calcium hypochlorite in the mixing tank and allowing the recommended 24 hours of settling before transferring the solution to the storage tank, the recurrence of this problem can be eliminated.

(4) Failure Mode - The chloride injection pump began leaking on 15 June. The problem was caused by a combination of seal wear caused by the pumping of the granular, undissolved portion of the calcium hypochlorite mixture and the corrosiveness of the hypochlorite solution on the impeller shaft.

Corrective Action - The leaking could be temporarily stopped by replacing the pump seals. However, on 9 July the pump began leaking so badly that no chlorine was reaching the macerator/detention tank. It was discovered that the pump impeller shaft was now pitted so badly that it had to be replaced along with the pump seals.

(5) Failure Mode - A reduction in the macerator shaft rotation speed was noticed by the operator during a routine inspection of the system on 9 July. The rotation was not yet restricted enough to trip the jam relay but it was audibly apparent that a problem existed.

Corrective Action - After removing the macerator blade assembly, electrician's tape was found tangled around the lower macerator blades. The tape was removed and normal operation resumed.

CORRECTIVE AND PREVENTIVE MAINTENANCE

The test plan required selection of corrective and preventive maintenance (PM) repairs and simulations in accordance with procedures outlined in section A10.3.2 of MIL-STD-471.[9] However, due to the lack of reliable CM action data and the lack of prior testing, it was impossible to predict which components of the system were most likely to fail. Available Maintenance and Material Management (3-M) and Consolidated Casualty Report System (CASREPT) data for 16 Fleet ships equipped with the C/M are contained in appendix C.

The selection of simulated and induced failures was based upon recommended troubleshooting procedures outlined in the C/M technical manual.[5] All the failures chosen are discussed there in detail, and thus, it was inferred that they were the most likely to occur.

Computations of maximum time to repair are included in appendix C.[10] The reject decision was based upon the 10 CM actions, as shown in table 2-C. These actions consisted of repair times for both the failures which occurred during the 1150-hour test and the additional induced or simulated failures required for the maintainability demonstration. For purposes of comparison, table 1-C shows the results of calculations based only upon the actual repair actions which occurred during the 1150-hour test. A reject decision can also be made in this case. The MTTR values for tables 1-C and 2-C are 27 and 35 minutes, respectively.

The only preventive maintenance practiced on the C/M system was to prohibit the throwing of paper towels and cigarette butts in the water closets. Although periodic inspections were made of the motors and other electrical components, the chlorination, maceration, or control subsystems were rarely, if ever, serviced. No PM schedule is recommended in the operating instructions manual. This manual was found adequate for both system operation and troubleshooting.

CONCLUSIONS

The Carlson Mark 10 chlorinator/macerator sewage treatment system aboard USS FIDELITY (MSO 443) was evaluated from 14 May 1973 through 10 July 1973, for a total of 1150 hours of on-line time. The system treated more than 16,000 gallons of water closet flush water. However, an almost equal amount of water leaked through the macerator from other sources.

MIL-S-24201B(SHIPS) requires that no more than 10% of the effluent samples show a coliform bacteria MPN greater than 240/100 milliliters. Analysis of 99 effluent samples showed 38.4% were greater than 240. Residual chlorine in the effluent averaged 156 p/m. There was little change in suspended solids and settleable solids between chlorinated and unchlorinated waste.

The system was required to demonstrate a 500-hour MTBF for 1150 hours of operating time. It demonstrated a MTBF of 88.5 hours at 90% confidence.

The maintainability evaluation required analysis of 10 CM actions. Computation of MTTR for those actions showed the system would not meet the maintainability demonstration criterion. The maximum repair time during the 1150-hour test was 2 hours and 40 minutes. This was within the 5-hour limit imposed by the test plan.

Therefore, the chlorinator/macerator does not comply with military standards for effluent quality or test plan requirements for reliability and maintainability.

RECOMMENDATIONS

To bring the unit into compliance with military standards, it will be necessary to reduce the coliform bacteria in the effluent. This can be accomplished by increasing either the chlorine contact time or the amount of chlorine injected per flush. Increasing contact time is impractical because it is dependent upon the frequency and volume of flushes from the water closets. Therefore, the practical solution is to increase the amount of chlorine injected into the macerator/detention tank. However, this should not be done without considering any possible harmful effects which may result from discharging highly chlorinated effluent into the marine environment.

The maintainability of the system can be enhanced by instituting a simple preventive maintenance program. Its major emphasis should be toward regular inspection and/or replacement of injection pump parts; periodic cleaning and flushing of the mixing, storage, and macerator/detention tanks; and a more comprehensive program to prevent the flushing of unacceptable materials through the water closets.

TECHNICAL REFERENCES

1 - "Environmental Protection Agency Performance Standards for Marine Sanitation Devices," Federal Register 40 CFR 140, 37 FR 12391 (20 June 1972)

2 - "Coast Guard Advance Notice of Rulemaking to Govern Marine Sanitation Devices," Federal Register 38 FR 15918 (18 June 1973)

3 - D'Emidio, Captain Joseph A., CEC, USN, "The Present and Future Programs of the U. S. Navy in Pollution Control," Pollution Control in the Marine Industries, Thomas F. P. Sullivan, ed. (1973)

4 - Fisk, D. J., and H. H. Singerman, "Proposed Revision of Military Specification MIL-S-24201 (SHIPS) Sewage Treatment Equipment Chlorinator-Macerator for Naval Shipboard Use," NSRDC Rept MATLAB 373 (Sep 1969)

5 - "Installation and Operating Instructions for Mark 10 Sewage Treatment Equipment, Koehler-Dayton, Inc., Dayton, Ohio," NAVSHIPS Tech Manual 0936-014-6010 (1 May 1969)

6 - Tarras, M. J., et al (ed.), Standard Methods for the Examination of Water and Wastewater, 13th Ed, New York, American Public Health Association (1971)

7 - Operational Test and Evaluation Force, Norfolk, Virginia, Inst 3930.1F, Vol. 2, p. 2-50 (13 Nov 1970)

8 - National Academy of Science Draft, "Water Quality Criteria-1972," Environment Reporter, p. 586 (10 Aug 1973), 1. 699 (17 Aug 1973)

9 - "Maintenance Demonstration, Department of Defense," MIL-Std 471 (15 Feb 1966 & 9 Apr 1968)

10 - Natrella, M. G., Experimental Statistics, Statistical Engineering Laboratory, National Bureau of Standards (1963)

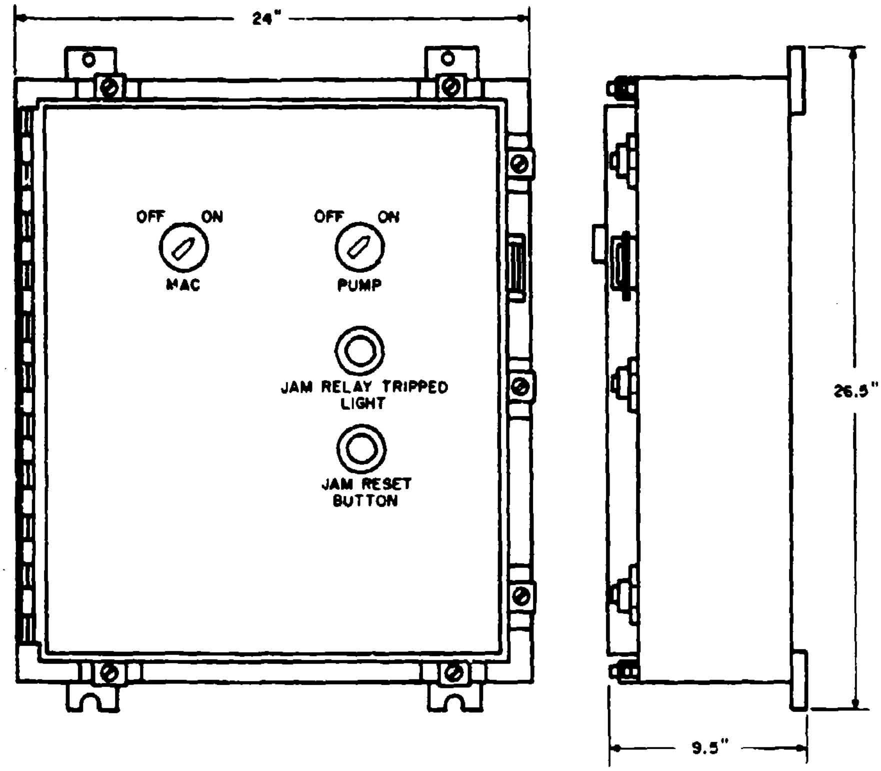

Figure 1(5)
Control Panel

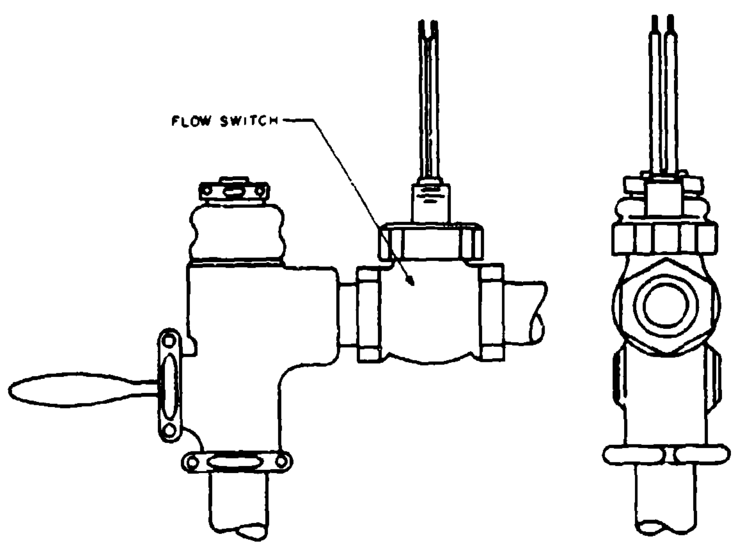

Figure 2(5)
Outline of Flow Switch

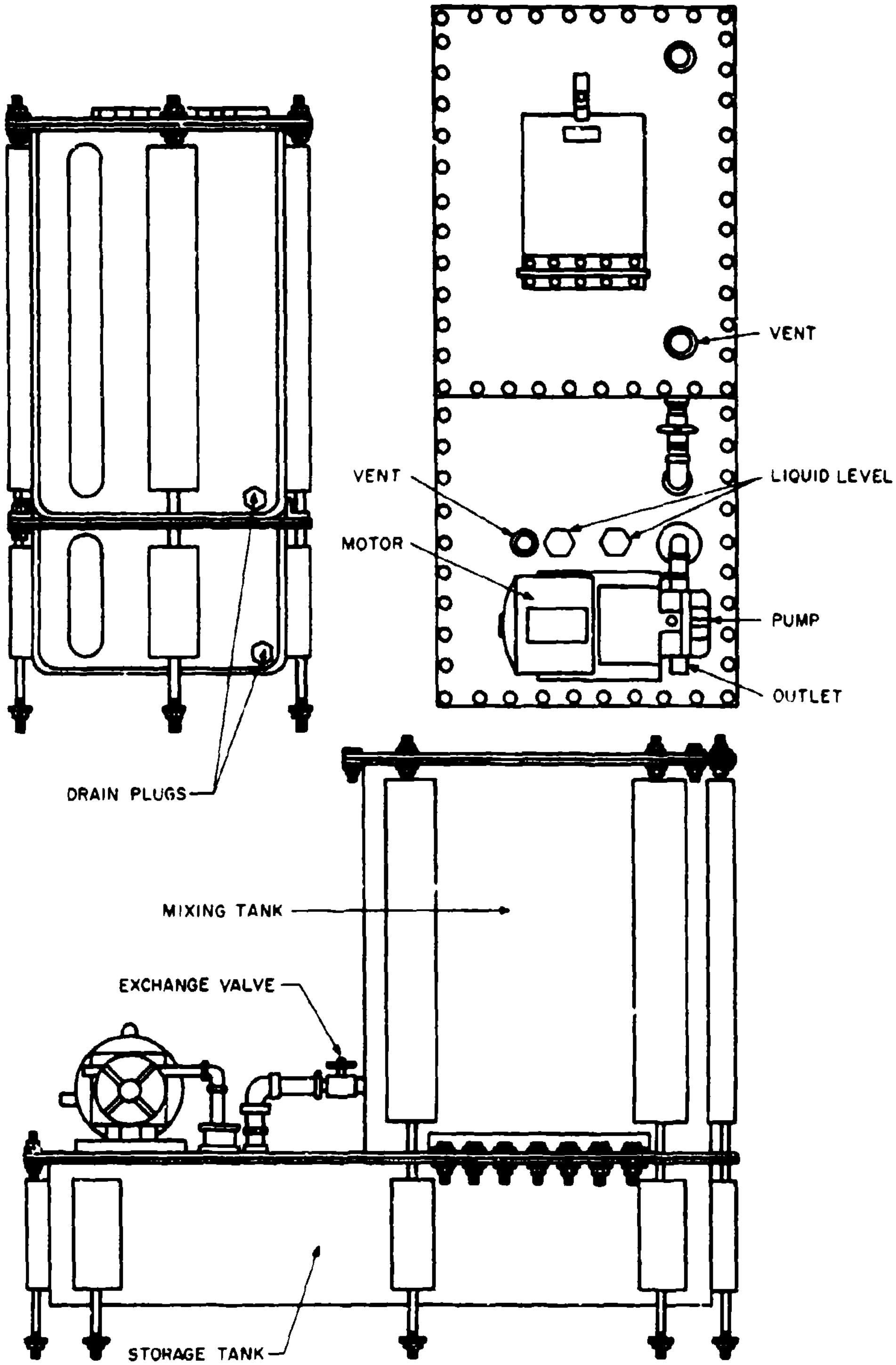

Figure 3(5)
Disinfectant Mixing and Storage Tanks

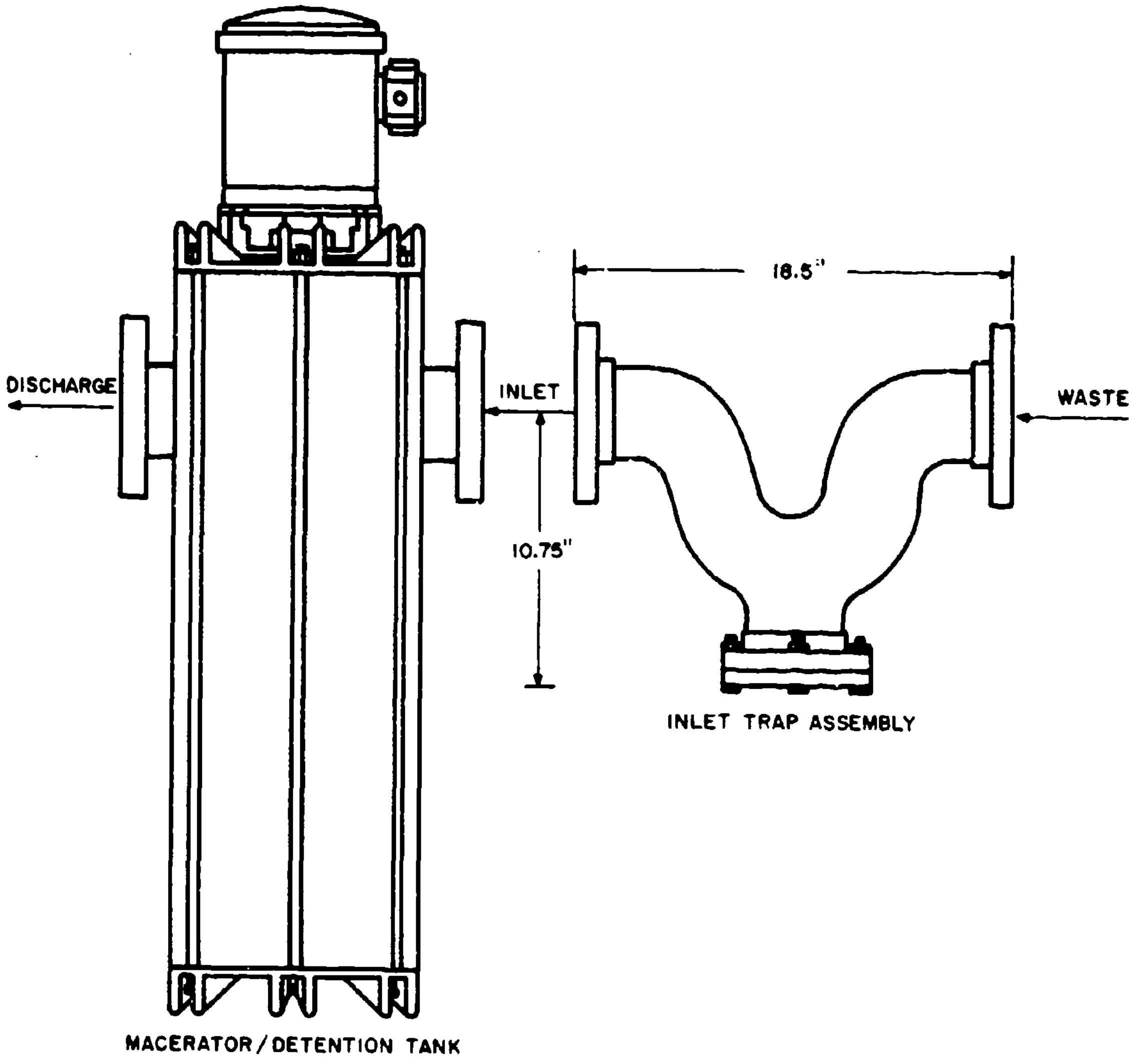

Figure 4[5]
Macerator/Detention Tank and Inlet Trap Assembly

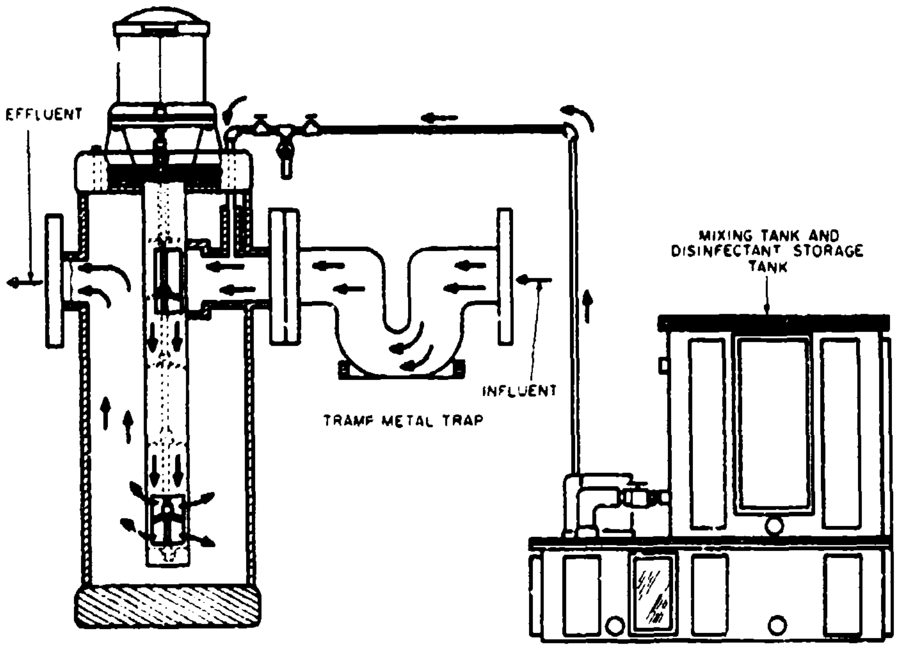

Figure 5
Diagram of Waste-Water Flow Through Chlorinator/Macerator

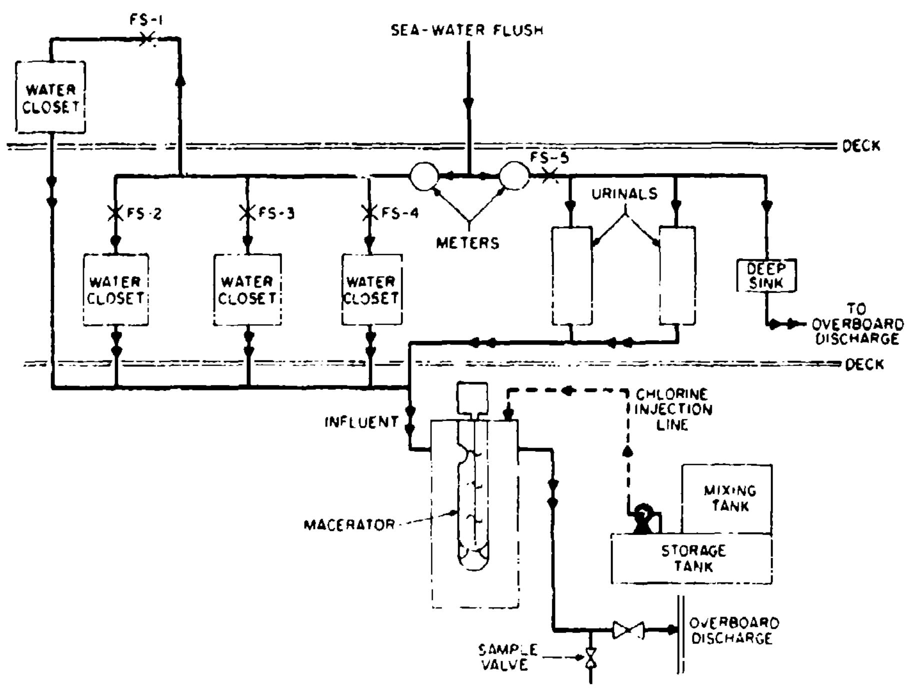

Figure 6
Schematic of Chlorinator/Macerator Shipboard Installation

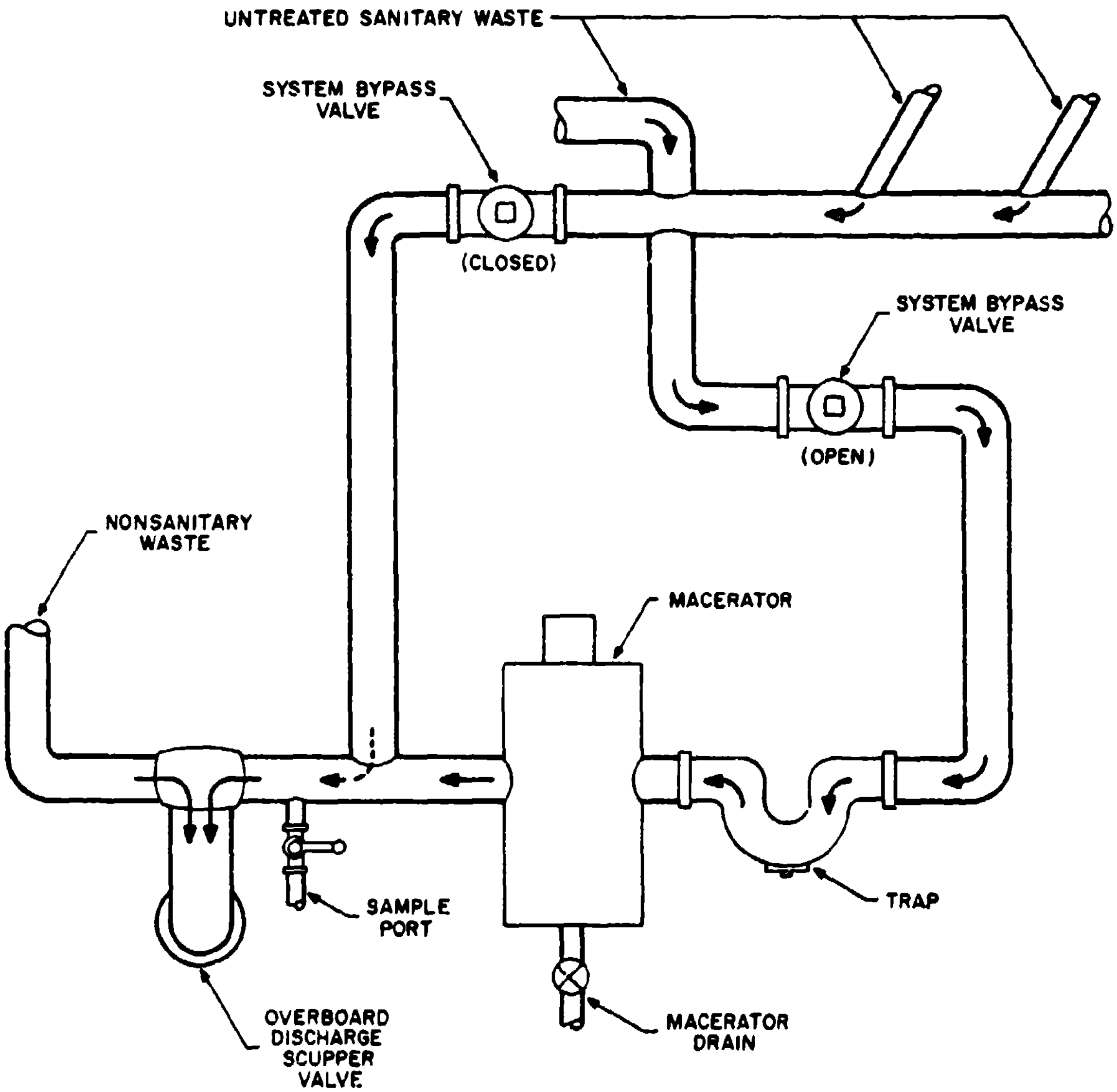

Figure 7
Piping Diagram for On-line System Operation

APPENDIX A

REPORT FORMS USED DURING RELIABILITY/MAINTAINABILITY EVALUATIONS

28-939

HOURLY LOG

Date____________ Location: At Sea______ In Port______

Time of Readings: In______________ Out_______________

Meter/Counter Readings

Water Closet #1_____________ Urinal #1____________
Water Closet #2_____________ Urinal #2____________
Water Closet #3_____________ Urinal #3____________
Water Closet #4_____________

Water Closet Flush Water Meter________________
Urinal Flush Water Meter_____________________

Chlorinator Insection Pump Elapsed Time_____________
Macerator Elapsed Time______________

Remarks:

Initials of Operator/
Recorder________

MAINTAINABILITY/HUMAN FACTORS FAILURE REPORT

Contract Number ____________________ Form Number ________________

1. Date of Failure ____

2. Elapsed Time at Time of Failure ____________________ hours

   Elapsed Cycles at Time of Failure ____________________ cycles

3. Failed Piece Part of Item (Name and Identification) ________________

   Primary ____

   Secondary ____

4. Cause of Failure (Design, Workmanship, Human, Unknown, Wear-Out, Other; Explain) ____

   ____

   ____

4a. No. of previous failures of same part in testing period ______________

5. First Indication of Malfunction (Did Anyone Observe the Failure ?)

   ____

   ____

6. Mode of Operation When Failure Occurred ________________________

   ____

7. Effect of Failure on Part ______________________________________

   ____

8. Effect of Failure on System ____________________________________

   ____

9. Detailed Failure Analysis ______________________________________

   ____

10. Repair Action (or Action Taken to Correct Deficiency)--(e.g. Correct, Replace, Eliminate, Modify, Design, Modify Part, Other; Describe Concisely the Action Taken) ____

   ____

10a. Describe any change in maintenance requirements as result of repair action

____

____

11. Verification Action Planned to Check Adequacy of Corrective Action __________

____

12. Cost of Repair Parts (or Remedy) ______________________________

____

13. Skill Level Required to Repair Failed Item ______________________

____

14. Diagnostic Time to Isolate Trouble __________ hours __________ min.

* Actual Time to Repair __________ hours __________ min.

Man-Hours to Repair __________ hours __________ min.

**Down Time __________ hours __________ min.

15. Scheduled (Preventive) Maintenance Associated with Failed Part

____

16. Name of Reporter ______________________________________

* Actual Time to Repair is the length of time spent in determining the problem and repairing the machine.

**Down Time is the length of time that the unit is not operational. It includes such times as time away from repair due to meals, holidays, waiting for ordered parts and administrative delays.

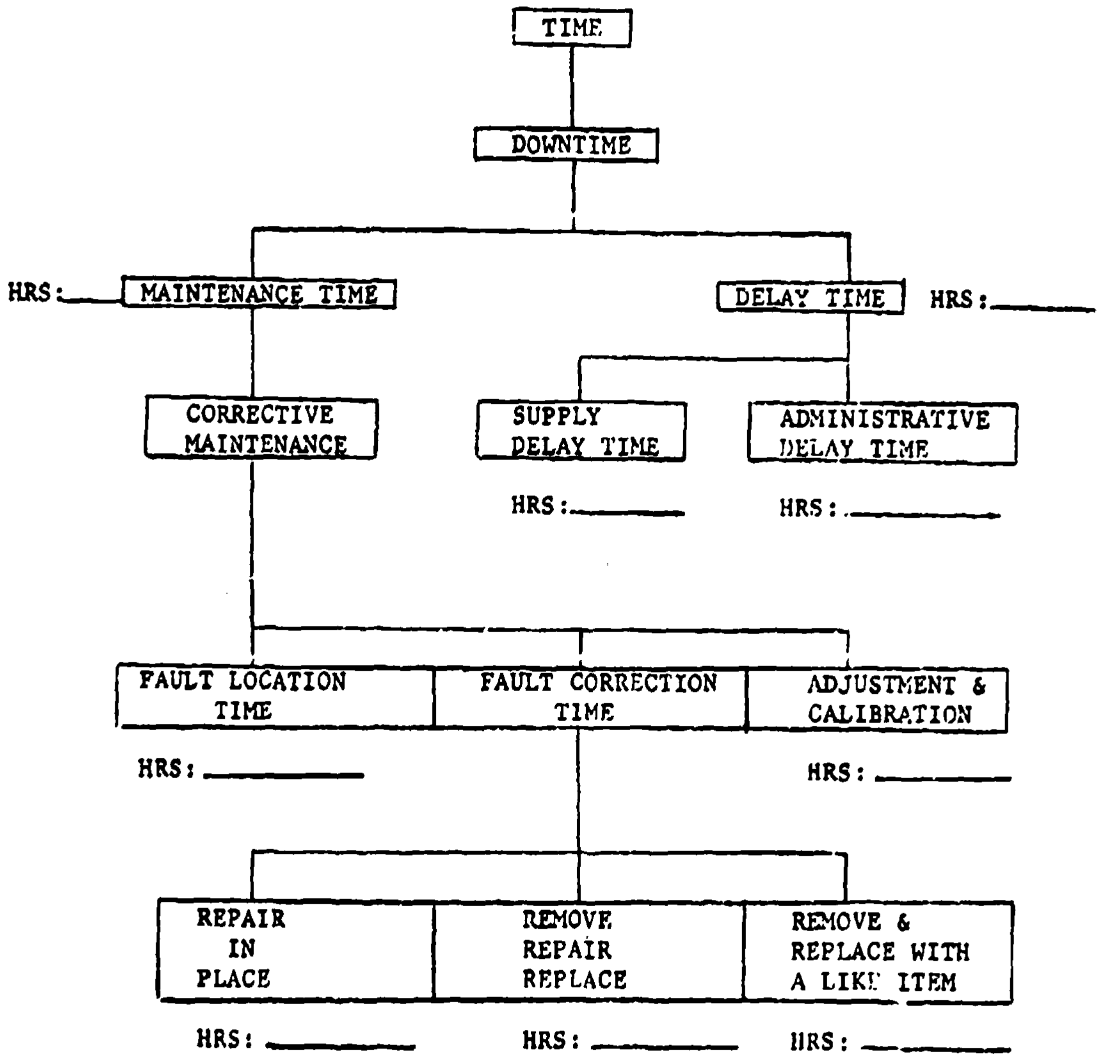

Figure 1-A
Time Relationship Diagram

Maintainability Evaluation Form

Remove/Replace ______ Hours ______________ Minutes

Actual Time to Remove/Replace ______ Hours ______________ Minutes

Man-Hours to Remove/Replace ______ Hours ______________ Minutes

Down Time ______ Hours ______________ Minutes

Tools Used: ____

Parts Used: ____

Adequacy of Technical Manual: ____

Skills Used: ____

Scheduled (Preventive) Maintenance Associated with Part: ____

Comments: ____

Name of Reporter: ____

Actual time to repair is the length of time spent in removal and replacement.

Down time is the time that flush service would not be available.

APPENDIX B

PERFORMANCE EVALUATION CALCULATIONS

COMPUTATION OF GEOMETRIC MEAN VALUES FOR MF COLIFORM COUNTS

The method used for determining geometric mean is:

$$\log G = \frac{\Sigma \log x}{n},$$

where

G = geometric mean

X = MPN (MF) value per 100 ml

n = number of tests yielding MPN (MF) values.

INFLUENT COLIFORM, MF

Total (1)			Fecal (2)		
n	x	n log x	n	x	n log x
1	260,000	5.41497	1	96,000	4.98227
1	410,000	5.61278	1	152,000	5.18184
2	490,000	11.38040	1	167,000	5.22272
1	580,000	5.76343	1	181,000	5.25768
1	610,000	5.78533	2	236,000	10.74582
1	650,000	5.81291	1	275,000	5.43933
1	1,400,000	6.14613	1	300,000	5.47712
1	1,600,000	6.20412	2	500,000	11.39794
1	1,800,000	6.25527	1	990,000	5.99564
1	2,300,000	6.36173	1	1,020,000	6.00860
1	2,900,000	6.46240	1	1,100,000	6.04139
1	3,000,000	6.47712	1	2,500,000	6.39794
1	4,850,000	6.68574			
Σ14		Σ84.36233	Σ14		Σ78.14829

(1) 1/14 Σlog X = 6.02588; G = A log 6.02588 ∴ G = 1,061,000
(2) 1/14 Σlog X = 5.582021; G = A log 5.582021 ∴ G = 382,000

EFFLUENT TOTAL COLIFORM, MF

Best Case, <10 → 1 (1)			Worst Case, <10 → 10 (2)		
n	x	n log x	n	x	n log x
55	1	0.00000	55	10	55.00000
1	10	1.00000	1	10	1.00000
3	40	4.80618	3	40	4.80618
3	60	5.33445	3	60	5.33445
3	80	5.70927	3	80	5.70927
3	90	5.86272	3	90	5.86272
1	100	2.00000	1	100	2.00000
1	110	2.04139	1	110	2.04139
1	190	2.27875	1	190	2.27875
1	200	2.30103	1	200	2.30103
1	240	2.38021	1	240	2.38021
1	260	2.41497	1	260	2.41497
1	360	2.55630	1	360	2.55630
1	460	2.66276	1	460	2.66276
1	510	2.70757	1	510	2.70757
2	540	5.46478	2	540	5.46478
1	980	2.99123	1	980	2.99123
1	1,300	3.11394	1	1,300	3.11394
1	1,400	3.14613	1	1,400	3.14613
1	1,800	3.25527	1	1,800	3.25527
1	1,820	3.26007	1	1,820	3.26007
1	2,000	3.30103	1	2,000	3.30103
2	3,000	6.95424	2	3,000	6.95424
1	3,300	3.51851	1	3,300	3.51851
1	4,900	3.69020	1	4,900	3.69020
1	5,200	3.71600	1	5,200	3.71600
2	5,700	7.51174	2	5,700	7.51174
1	10,000	4.00000	1	10,000	4.00000
1	10,200	4.00860	1	10,200	4.00860
1	13,400	4.12710	1	13,400	4.12710
1	37,000	4.56820	1	37,000	4.56820
1	40,000	4.60206	1	40,000	4.60206
1	42,000	4.62325	1	42,000	4.62325
1	1,000,000	6.00000	1	1,000,000	6.00000
Σ99		Σ125.90795	Σ99		Σ180.90795

(1) $1/99\ \Sigma \log X = 1.27180$; $G = A \log 1.27180$ ∴ $G = 19$

(2) $1/99\ \Sigma \log X = 1.82735$; $G = A \log 1.82735$ ∴ $G = 67$

EFFLUENT FECAL COLIFORM, MF

Best Case, <10 → 1 (1)			Worst Case, <10 → 10 (2)		
n	x	n log x	n	x	n log x
60	1	0.00000	60	10	60.00000
3	20	3.09309	3	20	3.09309
1	24	1.38021	1	24	1.38021
1	34	1.53148	1	34	1.53148
1	36	1.55630	1	36	1.55630
3	40	4.80618	3	40	4.80618
1	46	1.66276	1	46	1.66276
1	70	1.84510	1	70	1.84510
1	82	1.91381	1	82	1.91381
1	84	1.92428	1	84	1.92428
1	94	1.97313	1	94	1.97313
1	100	2.00000	1	100	2.00000
1	200	2.30103	1	200	2.30103
1	290	2.46240	1	290	2.46240
1	360	2.55630	1	360	2.55630
2	400	5.20412	2	400	5.20412
1	440	2.64345	1	440	2.64345
1	450	2.65321	1	450	2.65321
2	750	2.87506	2	750	2.87506
1	760	5.76162	1	760	5.76162
1	1,110	3.04532	1	1,110	3.04532
1	1,120	3.04922	1	1,120	3.04922
1	1,300	3.11394	1	1,300	3.11394
1	1,900	3.27875	1	1,900	3.27875
1	2,000	3.30103	1	2,000	3.30103
1	2,100	3.32222	1	2,100	3.32222
1	2,200	3.34242	1	2,200	3.34242
1	2,960	3.47129	1	2,960	3.47129
1	3,750	3.57403	1	3,750	3.57403
1	5,000	3.69897	1	5,000	3.69897
1	15,400	4.18756	1	15,400	4.18756
1	16,400	4.21484	1	16,400	4.21484
1	16,500	4.21748	1	16,500	4.21748
1	1,000,000	6.00000	1	1,000,000	6.00000
Σ99		Σ102.77056	Σ99		Σ162.77056

(1) 1/99 Σlog X = 1.03809; G = A log 1.03809 ∴ G = 11
(2) 1/99 Σlog X = 1.644147; G = A log 1.644147 ∴ G = 44

APPENDIX C

COMPUTATION OF MAXIMUM TIME TO REPAIR

There is a 90% probability that at least 95% of the logs of the repair times will be less than T. Assuming a log-normal distribution for CM repair times;

$$T = \overline{X} + Ks ,$$

where

$\overline{X}$ = mean of the logs of the observed CM repair times (antilog $\overline{X}$ is the mean time to repair for CM actions used)

s = standard deviation of the logs of the CM repair times.

K = factor for one-sided tolerance limit for normal distribution.[1]

Accept/Reject Criterion

Accept	Reject
$T \leq \log 5$ Hours	$T > \log 5$ Hours

Log 5 Hours = log 300 minutes = 2.4771.

TABLE 1-C
COMPUTATION OF MAXIMUM TIME TO REPAIR FOR THE EIGHT ACTUAL CM REPAIR ACTIONS SHOWN IN TABLE 4 OF THE TEXT

Action	Time, min	Log
1	280	2.4472
2	5	0.6990
3	5	0.6990
4	10	1.0000
5	30	1.4771
6	120	2.0792
7	51	1.7076
8	19	1.2788
Therefore:		Σ = 11.3879
MTTR = Anti log $\overline{X}$ = 27 minutes		$\overline{X}$ = 1.4234
T = 1.4234 + 2.755 (.5927)		s = 0.5927
= 3.0562		
T = 3.0562 > 2.4771 → Reject		

[1]Natrella, M. G., Experimental Statistics, table A-7, Statistical Engineering Laboratory, National Bureau of Standards (1963)

TABLE 2-C
COMPUTATION OF MAXIMUM-TIME-TO-REPAIR FOR THE
10 CM REPAIR ACTIONS SHOWN IN TABLE 5 OF THE TEXT

Action	Time, min	Log
1	5	0.6990
2	10	1.0000
3	25	1.3979
4	58	1.7634
5	56	1.7482
6	150	2.1761
7	40	1.6128
8	173	2.2380
9	34	1.5315
10	19	1.2788
Therefore:		$\Sigma = 15.4457$
MTTR = Antilog $\overline{X}$ = 35 minutes		$\overline{X} = 1.5446$
$T = 1.5446 + 2.568\ (0.4557)$		$s = 0.4557$
$T = 2.7148 > 2.4771 \rightarrow$ Reject		

0451:JH:dma
Ser 166-045
6 Mar 1973

C O P Y

From: Commander, Naval Ship Systems Command
To: Commander, Naval Ship Research and Development Center
Annapolis Laboratory

Subj: Macerator-Chlorinator Sewage Treatment System 3-M Maintenance Data; lack of

Ref: (a) NSRDC/A ltr 286:AT 9360 Work Unit 2860-511 of 26 Feb 1973

1. Reference (a) requested 3-M (Maintenance and Material Management) and CASREPT (Consolidated Casualty Report System) data for the subject sewage treatment systems. The system of interest is manufactured by Koehler-Dayton Incorporated, APL (Allowance Parts List) number 670280013, NAVSHIPS Technical Manual Number 0936-014-6010.

2. Our records indicate that the data in the 3-M/CASREPT files is not sufficient to make ordering the data products requested by reference (a) worthwhile. However, for your information the following is provided for master APL 670280013:

		MDCS	CASREPTS	
	670280013	1 SHIP, 2 ACTIONS	1 SHIP, 1C2	1 JAN 70 thru 31 DEC 72
PUMP	019110043	1 SHIP, 2 ACTIONS	0	" " " " " " "
MOTOR	175504308	0	0	" " " " " " "
MACERATOR	175504309	2 SHIPS, 3 ACTIONS	0	" " " " " " "
SWITCH	213480273	0	0	" " " " " " "
SWITCH	213480274	3 SHIPS, 5 ACTIONS	0	" " " " " " "
PANEL CONTROL	500840015	0	0	" " " " " " "
TANK	920600002	0	0	" " " " " " "
TANK	920600007	1 SHIP, 1 ACTION	0	" " " " " " "

3. The laboratory's interest in using the Maintenance Data Collection Sub-System (MDCS) of the 3-M system is appreciated, and it is hoped that you will continue to use the 3-M/CASREPT data bank to assist you in your assigned work problems.

Copy to:
CNO (OP433)
CNM (MAT 0414)
CINCPACFLT (3-M office)
CINCLANTFLT (3-M office)

A. J. Ruffini
By direction

APPENDIX D
CHRONOLOGICAL SUMMARY OF EVENTS, EQUIPMENT ELAPSED TIMES, AND FLUSH COUNTER READINGS

Date 1973	Time	System Down-time hr	Elapsed Time into Test hr	Elapsed Time of Macerator Operation hr	Flushes to Date	Event
14 May	0000	-	0	-	-	Formal start of 1150-hour evaluation
14 May	1700	None	7.00	0.58	281	Mix new batch of calcium hypochlorite
17 May	0610	10.6	78.17	2.28	776	Critical failure, macerator clogged with paper towels and mop strings
17 May	1400	None	-	-	-	Urinals put on-line by USS FIDELITY crew
17 May	1730	None	79.00	2.48	792	Mix new batch of calcium hypochlorite
18 May	0930	0.08	95.00	2.94	860	Critical failure, disinfectant storage tank empty
24 May	1530	None	244.92	10.65	1027	Mix new batch of calcium hypochlorite
25 May	0900	1.00	262.42	10.66	1664	Critical failure, disinfectant storage tank empty
7 June	1400	None				Urinals secured by USS FIDELITY crew
8 June	0930	None	597.92	21.12	2726	Mix new batch of calcium hypochlorite
10 June	0400	61.92	640.42	22.91	2863	Critical failure, clogged chlorine injection line
15 June	0700	0.5	701.50	27.41	3150	Major failure, leaky chlorine injection pump, disinfectant was still being pumped to macerator
15 June	1320	None	707.83	-	-	Mix new batch of calcium hypochlorite
19 June	1110	107.91	801.87	30.96	3079	Critical failure, macerator clogged with paper towels
26 June	1345	None	-	-	-	Mix fresh batch of calcium hypochlorite, unit still off line
9 July	1320	None	1115.92		4980	Mix new batch of calcium hypochlorite
9 July	1600	0.87	1118.58	43.72	4991	Major failure, low macerator r/min, electricians' tape wrapped around blades.
9 July	1652	0.32	1118.58	43.72	4991	Critical failure, badly leaking chlorine injection pump, no disinfectant reaching macerator
11 July	0018	-	1150.0	47.8	5258	End of test

APPENDIX E

LABORATORY ANALYTICAL RESULTS

MACERATED RAW WASTE-WATER SAMPLES

Sample No.	Settleable Solids ml/l	Suspended Solids mg/l	Total Coliform MF No./100 ml	Fecal Coliform MF No./100 ml	Total Coliform MPN/100 ml	Fecal Coliform MPN/100 ml	Residual Chlorine p/m
			11 May 1973				
1	38	2292	650,000	275,000	>1100	>1100	0
2	32	452	580,000	236,000	>1100	>1100	0
3	12	292	410,000	152,000	>1100	>1100	0
4	28	644	490,000	167,000	>1100	>1100	0
5	20	520	610,000	236,000	>1100	>1100	0
6	19	444	260,000	96,000	>1100	>1100	0
7	30	436	490,000	181,000	>1100	>1100	0
8	61	936	2,300,000	990,000	>1100	>1100	0
9	190	2672	3,000,000	1,020,000	>1100	>1100	0
10	65	736	4,850,000	2,500,000	>1100	>1100	0
			22 May 1973				
1	80	408	1,800,000	500,000	>1100	>1100	0
2	110	460	1,600,000	500,000	>1100	>1100	0
3	80	420	2,900,000	1,100,000	>1100	>1100	0
4	120	284	1,400,000	300,000	>1100	>1100	0

CHLORINATOR/MACERATOR EFFLUENT

Sample No.	Settleable Solids ml/l	Suspended Solids mg/l	Total Coliform MF No./100 ml	Fecal Coliform MF No./100 ml	Total Coliform MFN/100 ml	Fecal Coliform MPN/100 ml	Residual Chlorine p/m
				14 May 1973			
1	220	4144	< 10	< 10	< 3	< 3	232
2	130	1840	< 10	< 10	< 3	< 3	180
3	130	1780	< 10	< 10	< 3	< 3	146
4	24	544	< 10	< 10	< 3	< 3	188
5	19	392	< 10	< 10	< 3	< 3	360
6	130	1488	< 10	< 10	< 3	< 3	224
7	60	992	< 10	< 10	< 3	< 3	212
8	52	612	< 10	< 10	< 3	< 3	176
9	59	1004	< 10	< 10	< 3	< 3	184
10	61	1096	< 10	< 10	< 3	< 3	164
				15 May 1973			
1	160	1396	40	24	93	43	114
2	85	884	< 10	< 10	< 3	< 3	192
3	140	2336	< 10	< 10	< 3	< 3	215
4	46	924	< 10	< 10	< 3	< 3	240
5	85	1152	< 10	< 10	< 3	< 3	192
6	56	812	< 10	< 10	< 3	< 3	187
7	36	312	< 10	< 10	< 3	< 3	230
8	110	1388	< 10	< 10	< 3	< 3	219
9	90	1104	< 10	< 10	< 3	< 3	186
10	58	668	< 10	< 10	< 3	< 3	190
				16 May 1973			
1	48	504	40	36	93	93	64
2	90	1076	< 10	< 10	< 3	< 3	166
3	75	840	< 10	< 10	< 3	< 3	228
4	120	1300	< 10	< 10	< 3	< 3	148
5	150	1868	< 10	< 10	< 3	< 3	227
6	200	2572	< 10	< 10	< 3	< 3	226
7	130	1084	< 10	< 10	< 3	< 3	236
8	80	792	90	82	240	240	140
9	95	1044	110	100	240	240	178
10	80	1096	90	84	240	240	126

Sample No.	Settleable Solids ml/l	Suspended Solids mg/l	Total Coliform MF No./100 ml	Fecal Coliform MF No./100 ml	Total Coliform MPN/100 ml	Fecal Coliform MPN/100 ml	Residual Chlorine p/m
				18 May 1973			
1	46	292	5700	1900	1100	1100	37
2	50	320	260	94	240	240	90
3	75	560	190	70	240	93	61
4	34	704	100	46	240	240	57
5	58	380	< 10	< 10	< 3	< 3	104
6	50	516	90	34	240	240	65
7	50	924	< 10	< 10	< 3	< 3	109
8	18	236	1820	760	> 1100	> 1100	37
9	23	144	5700	2100	> 1100	> 1100	26
10	52	552	< 10	< 10	< 3	< 3	154
				19 May 1973			
1	70	568	< 10	< 10	< 3	< 3	646
2	75	492	< 10	< 10	< 3	< 3	83
3	58	332	< 10	< 10	< 3	< 3	273
4	25	312	< 10	< 10	< 3	< 3	619
5	80	960	13,400	5,000	> 1100	> 1100	130
6	75	664	10,200	3,750	> 1100	> 1100	63
7	60	324	980	360	460	460	45
8	44	516	3,000	1,110	> 1100	> 1100	32
9	25	184	1,800	760	> 1100	> 1100	30
10	60	332	10	< 10	23	< 3	65
				21 May 1973			
1	3	20	4,900	2,200	> 1100	> 1100	28
2	13	152	< 10	< 10	< 3	< 3	54
3	26	132	< 10	< 10	< 3	< 3	66
4	56	276	TNTC	TNTC	> 1100	> 1100	47
5	40	380	37,000	16,500	> 1100	> 1100	34
6	38	304	5,200	2,000	> 1100	> 1100	71
7	80	384	3,300	1,300	> 1100	> 1100	95
8	56	296	540	200	460	210	79
9	65	272	1,300	450	> 1100	> 1100	107
10	65	424	2,000	750	> 1100	> 1100	106

TNTC - Too numerous to count (i.e., 71,000,000).

Sample No.	Settleable Solids ml/l	Suspended Solids mg/l	Total Coliform MF No./100 ml	Fecal Coliform MF No./100 ml	Total Coliform MFN/100 ml	Fecal Coliform MPN/100 ml	Residual Chlorine p/m
22 May 1973							
Sample Destroyed							
2	85	808	< 10	< 10	< 3	< 3	159
3	75	820	< 10	< 10	< 3	< 3	275
4	75	648	3,000	1120	> 1100	> 1100	89
5	70	568	360	290	> 1100	> 1100	128
6	65	560	510	290	> 1100	> 1100	129
7	75	588	460	400	> 1100	> 1100	150
8	60	484	40	< 10	< 3	< 3	213
9	60	500	< 10	< 10	< 3	< 3	150
10	60	396	< 10	< 10	< 3	< 3	89
23 May 1973							
1	52	240	80	< 10	240	240	8
2	56	508	10,000	2960	> 1100	> 1100	29
3	70	644	1,400	440	> 1100	> 1100	75
4	70	1160	200	40	240	240	89
5	110	1240	60	< 10	240	240	65
6	75	944	< 10	< 10	< 3	< 3	89
7	75	1328	< 10	< 10	< 3	< 3	121
8	65	824	< 10	< 10	< 3	< 3	299
9	44	984	< 10	< 10	< 3	< 3	546
10	100	1224	< 10	< 10	< 3	< 3	231
24 May 1973							
1	56	540	80	20	> 1100	210	69
2	52	344	< 10	< 10	< 3	< 3	66
3	46	340	< 10	< 10	< 3	< 3	79
4	60	1460	40,000	16,000	> 1100	> 1100	48
5	70	1040	540	20	> 1100	210	62
6	48	764	42,000	16,400	> 1100	> 1100	27
7	50	448	60	40	160	120	164
8	65	464	80	20	290	210	165
9	65	628	< 10	< 10	< 3	< 3	86
10	85	332	< 10	< 10	< 3	< 3	707

Sample No.	Settleable Solids ml/l	Suspended Solids mg/l	Total Coliform MF No./100 ml	Fecal Coliform MF No./100 ml	Total Coliform MFN/100 ml	Fecal Coliform MPN/100 ml	Residual Chlorine p/m
				25 May 1973			
1	75	640	60	< 10	75	< 3	61
2	105	988	< 10	< 10	< 10	< 3	121
3	110	1264	240	40	240	240	143
4	40	608	< 10	< 10	< 3	< 3	119
5	60	664	< 10	< 10	< 3	< 3	120
6	70	604	< 10	< 10	< 3	< 3	103
7	70	620	< 10	< 10	< 3	< 3	80
8	20	260	< 10	< 10	< 3	< 3	451
9	16	464	< 10	< 10	< 3	< 3	397
10	36	624	< 10	< 10	< 3	< 3	222

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5. AUTHOR(S) (First name, middle initial, last name)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	NAVSEC

13. ABSTRACT

A technical evaluation of the Carlson Mark 10 chlorinator/macerator sanitary waste-water treatment system aboard USS FIDELITY (MSO 443) has been completed. The evaluation was to determine compliance with effluent quality standards set forth in MIL-S-24201B (SHIPS) and to obtain reliability and maintainability information.

The system treated 16,600 gallons of waste water during the 1150-hour test. Over 28% of the samples collected exceeded military standards for effluent coliform bacteria. There were eight failures resulting in a mean time between failure at 90% confidence of 88.5 hours. The maximum failure repair time was 2 hours and 40 minutes.

The chlorinator-macerator did not meet military standards or satisfy the test plan for reliability and maintainability. Effluent bacterial quality could be improved by increasing chlorination, but this would result in high levels of chlorine entering receiving waters. System downtime could be reduced by instituting a simple preventive maintenance program.

(Author)

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Shipboard wastes						
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